Electrical Power Engineering (2)

Code: EP2207

Lecture: 4 **Tutorial: 4** **Total: 8**

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ECONOMICS OF

POWER FACTOR

ECONOMICS OF POWER FACTOR

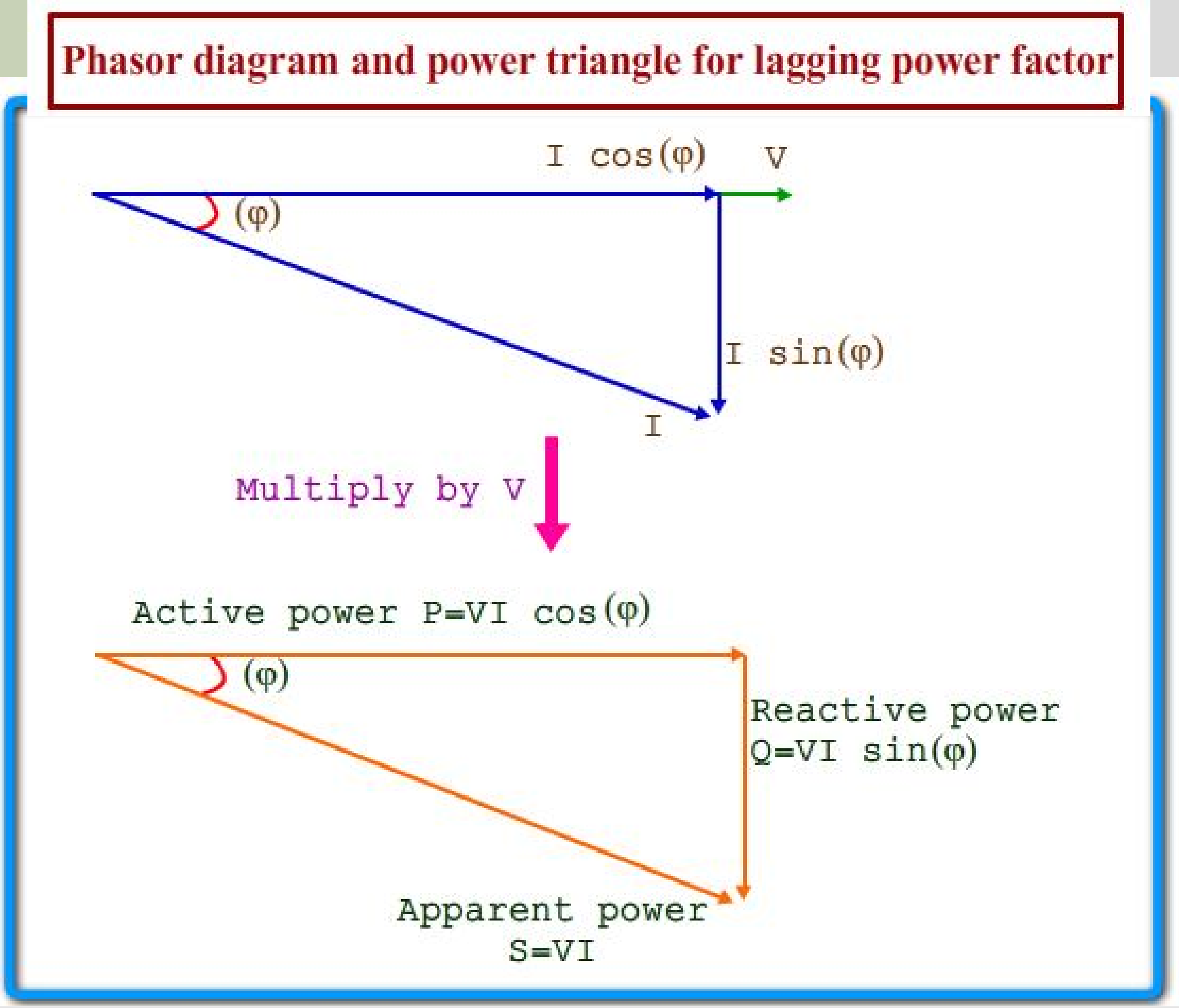
Reactive loads (inductive or capacitive) act to shift the current out of phase with the voltage

The cosine of the resulting angle between the current and voltage is the power factor

A poor power factor will result in higher current

Excessive losses along utility company feeder lines

ECONOMICS OF POWER FACTOR



ECONOMICS OF POWER FACTOR

$$PF = \cos(\phi) = \frac{P\ (kW)}{S\ (kVA)}$$

$$\sin(\phi) = \frac{Q\ (k\ var)}{S\ (kVA)}$$

Where:

ϕ is the phase angle
P (kW) is the true power
S (kVA) is the apparent power
Q (kvar) is the kilovolt-ampers-reactive component of an inductive circuit

The kvar component (also known as the phantom power) provides the magnetizing force necessary for operation of inductive loads.

ECONOMICS OF POWER FACTOR

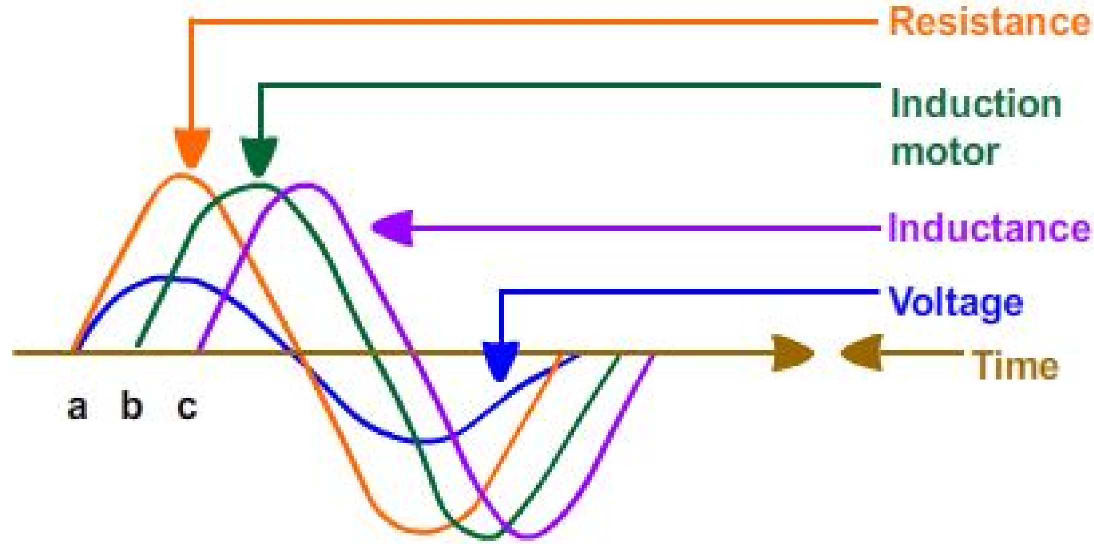
Current in resistive circuits is in phase with voltage

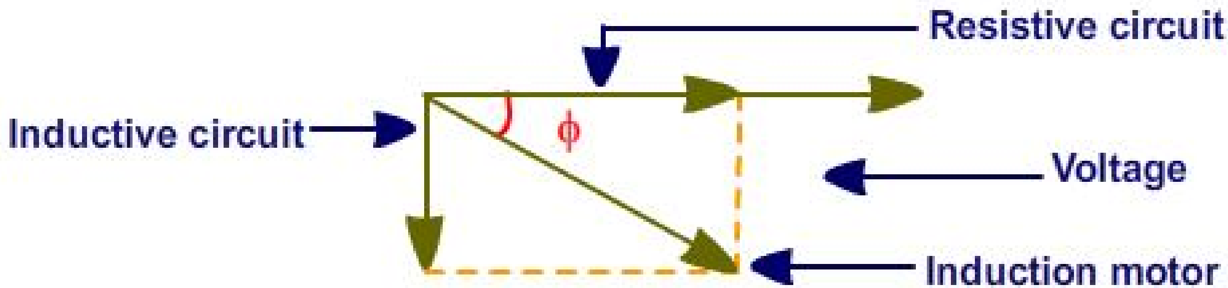
In a purely inductive circuit, the current lags the voltage by 90°

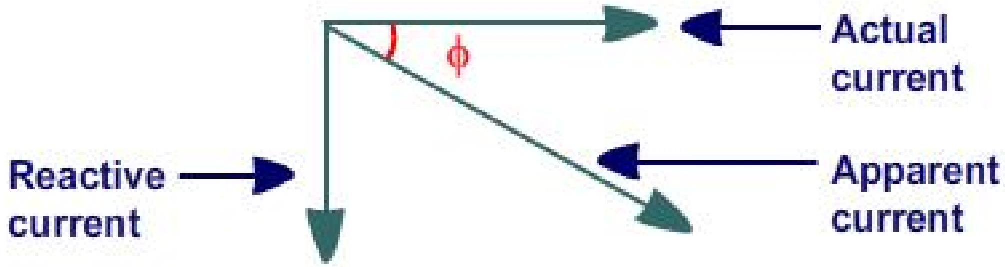
With both inductive and resistive components, the two conditions exist simultaneously

The power factor can be defined as the cosine of the angle (ϕ)

The greater the angle (ϕ), the lower the power factor


Resistance
Induction motor
Inductance
Voltage
Time
a b c


Resistive circuit
Inductive circuit
ϕ
Voltage
Induction motor


Actual current
ϕ
Reactive current
Apparent current

Power Factor Correction Techniques

The term "compensation" is used to describe the intentional insertion of reactive power devices, either capacitive or inductive, to achieve one or more desired effects in an electric power system

These effects include improved voltage profiles, enhanced stability, and increased transmission capacity

The devices are either in series or in parallel with load(s) at one or more point in power systems

Power Factor Correction Techniques

To keep the power factor as close as possible to unity, utility companies place capacitor banks in parallel with the load at various locations in the distribution system

This offsets the inductive loading (lagging power factor) of most user equipment

The goal is to create an equal amount of reactive power in the system to match the lagging PF of the load

Power Factor Correction Techniques

Capacitor banks are switched automatically to compensate for changing load conditions

In addition, static capacitors are used for power factor correction

The PF correction capacitors are connected in parallel with the utility lines as close as practical to the low-PF loads

Synchronous capacitors, on the other hand, can be adjusted to provide varying capacitance to correct for varying PF loads

Power Factor Correction Techniques

Power factor can be billed as one, or a combination, of the following

A charge on monthly kvar hours

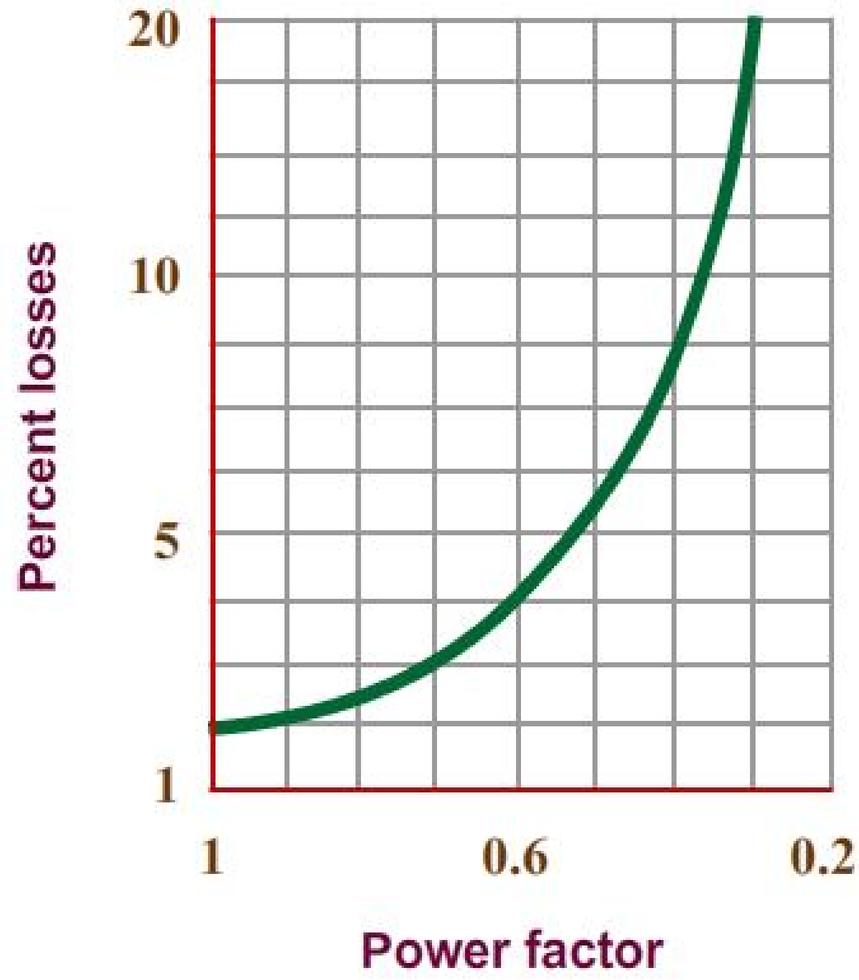
An increasing penalty for decreasing PF

A straight charge for the maximum value of kVA used during the month

A penalty for PF below a predetermined value or a credit for PF above a prede-termined value

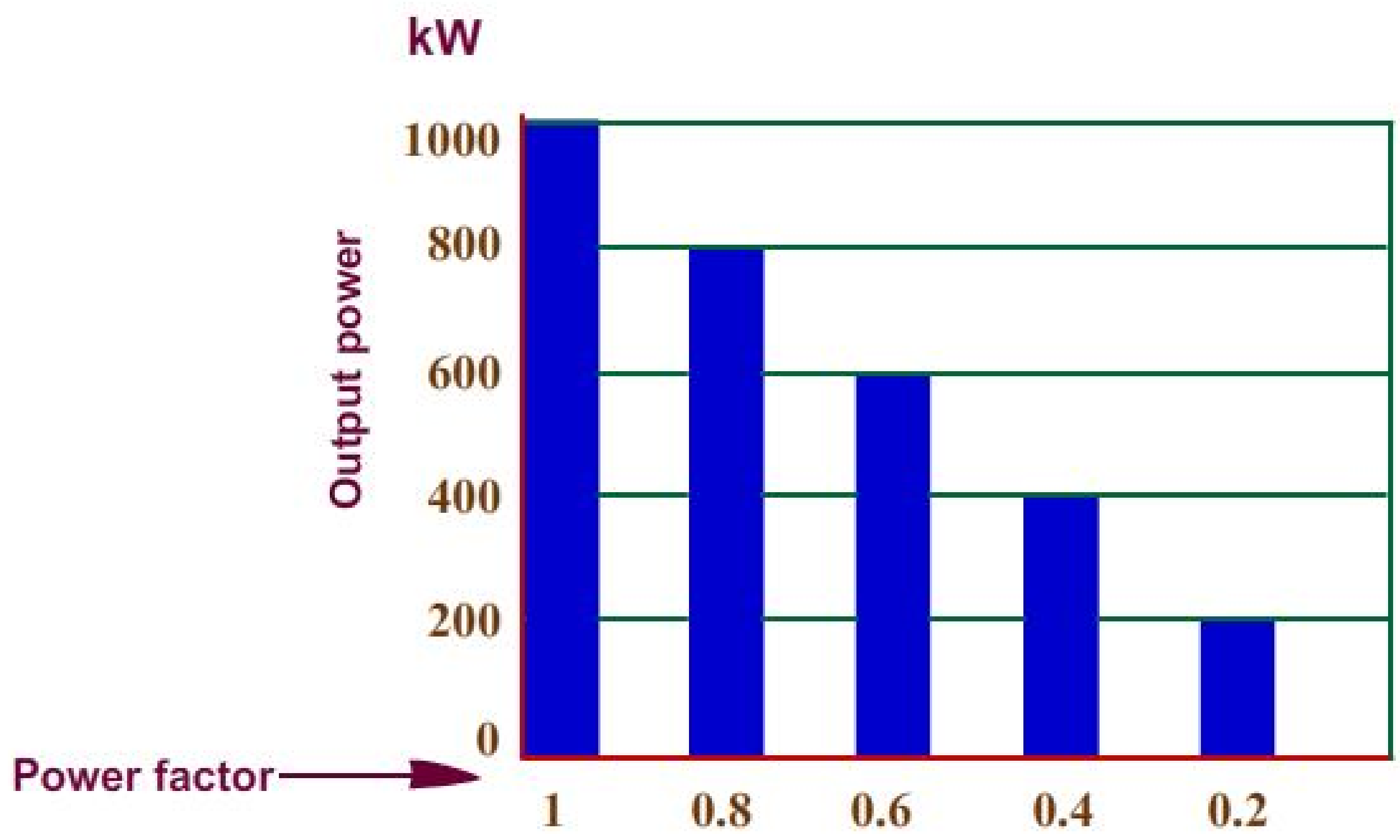
Power Factor Correction Techniques

Relationship between power factor and percentage losses



Power Factor Correction Techniques

Effects of power factor on the output of a transformer



$$\mathrm{VR} = \frac{\mathrm{k}\,var_{\mathrm{cb}} \cdot \mathrm{Z_t}}{\mathrm{kVA_t}}$$

VR: per cent voltage rise

$Kvar_{cb}$: sum of capacitor kvar ratings

Z_t: percent reactance of the supply transformer(s)

kVA_t: kVA rating of the supply transformer(s)

On-Site Power Factor Correction

Power factor can be improved in two ways

Reduce the reactive energy by eliminating low PF loads, e.g. unloaded motors and transformers

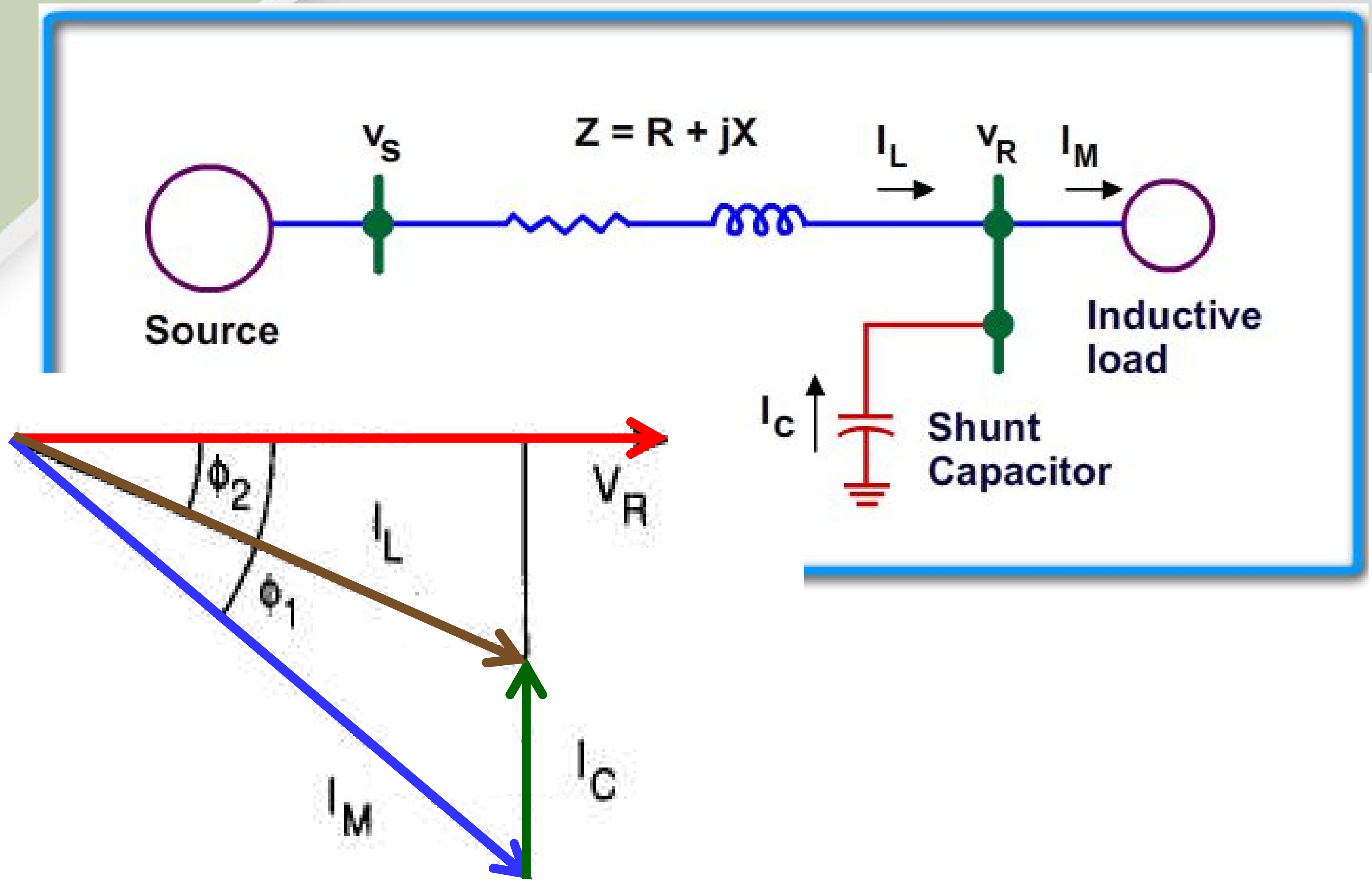
Apply external compensation capacitors or other devices to correct the low-PF condition

On-Site Power Factor Correction

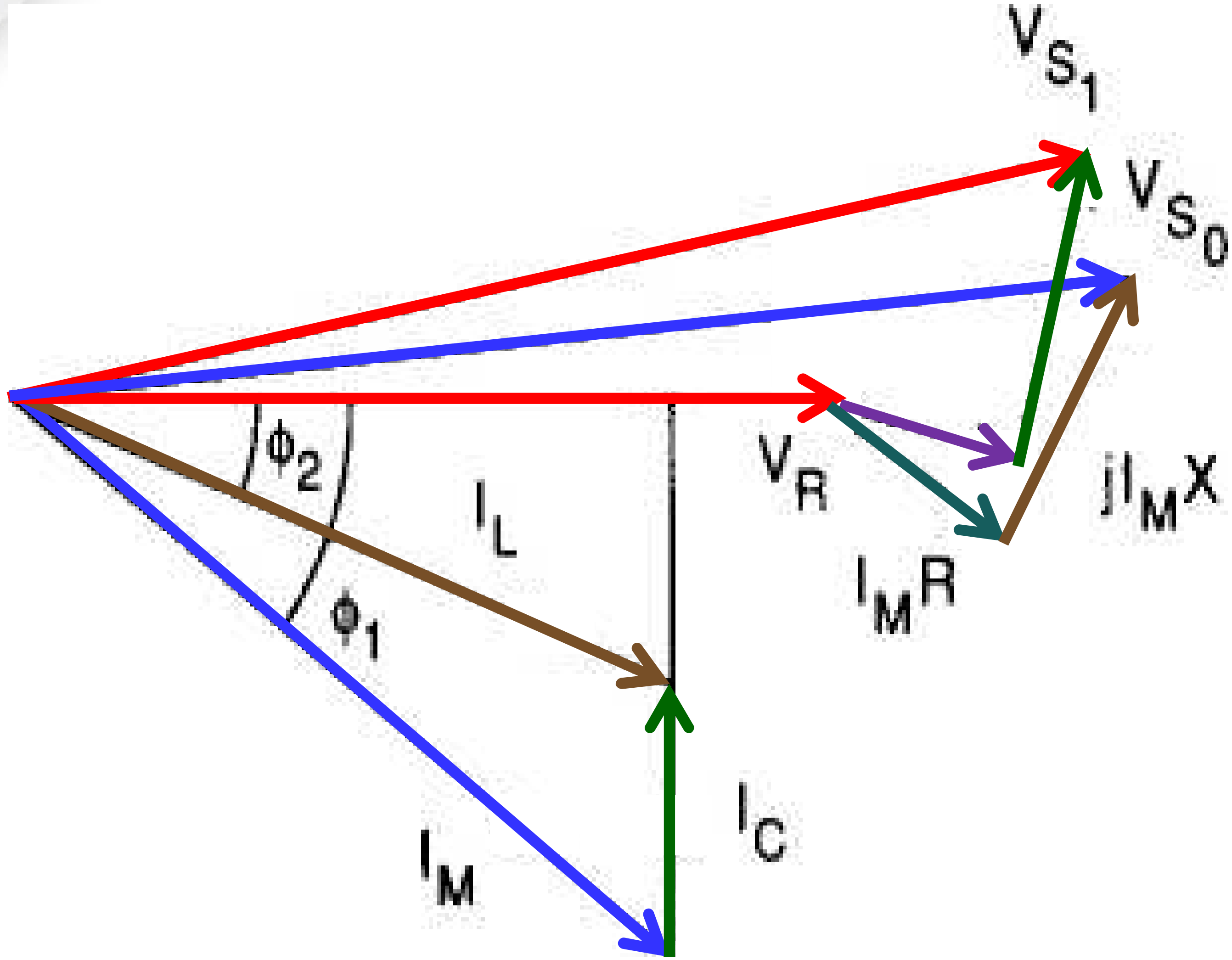
PF correction capacitors perform the function of an energy-storage device

Instead of transferring reactive energy back and forth between the load and the power source, the magnetizing current reactive energy is stored in a capacitor at the load

On-Site Power Factor Correction

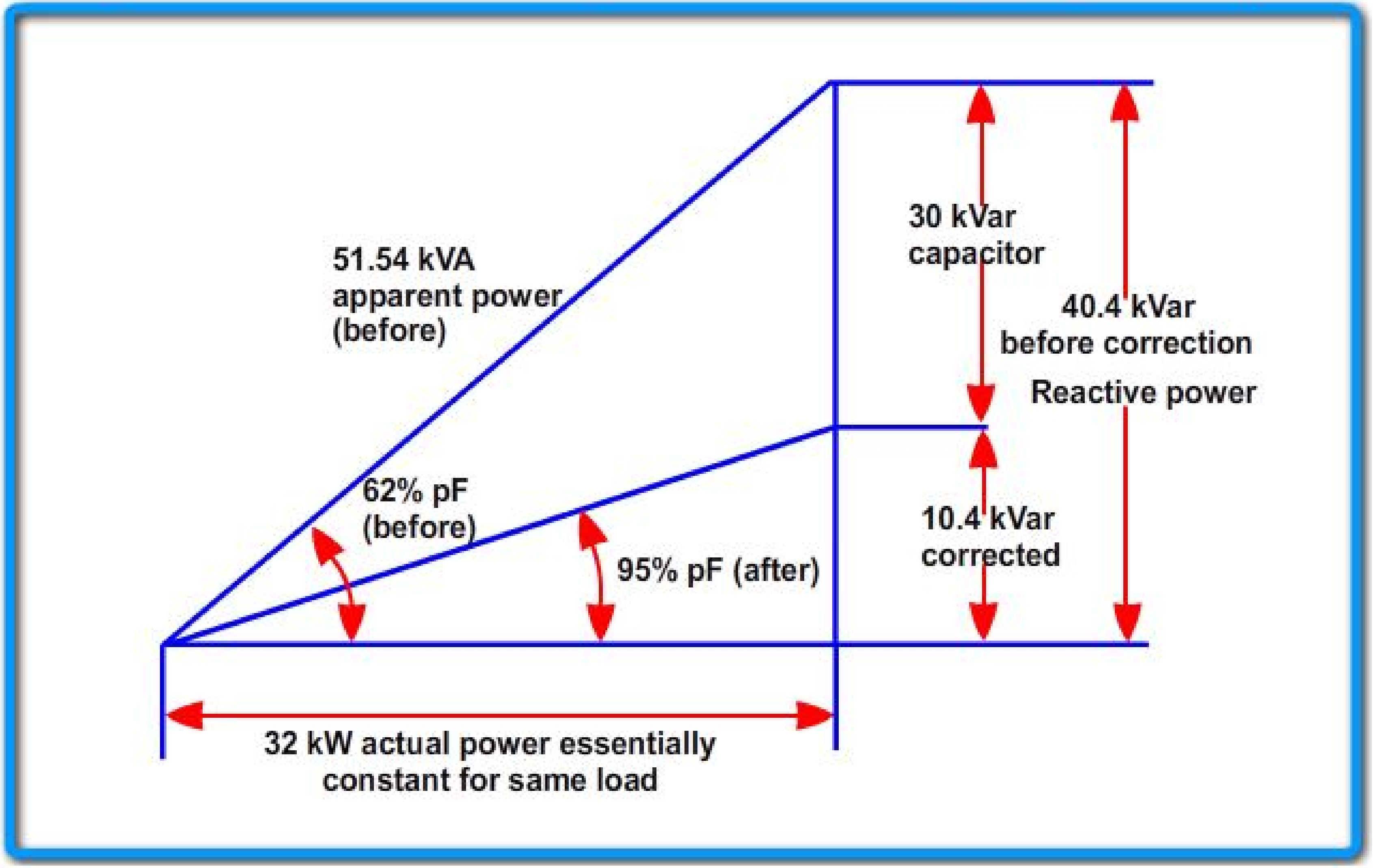


On-Site Power Factor Correction



On-Site Power Factor Correction

The correction of the power factor using capacitors



On-Site Power Factor Correction

Correction to 0.85 will satisfy many requirements

No economic advantage is likely to result from correcting to 0.95 or greater

Overcorrecting a load by placing too many PF correction capacitors can reduce the power factor after reaching unity, and cause uncontrollable overvoltages in low-kVA-capacity power sources

On-Site Power Factor Correction

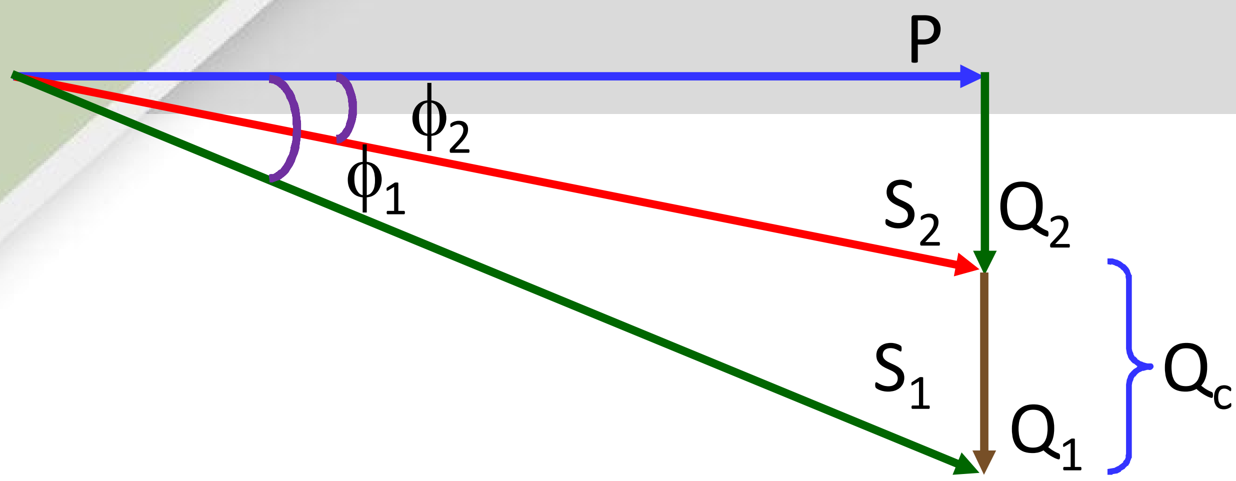
If the capacitors are switched on and off, they will create significant impulses of their own

Switching can be accomplished with acceptably low disturbance using soft-start or pre-insertion resistors

Such resistors are connected momentarily in series with the capacitors

After a brief delay (0.5 s or less), the resistors are short-circuited, connecting the capacitors directly across the line

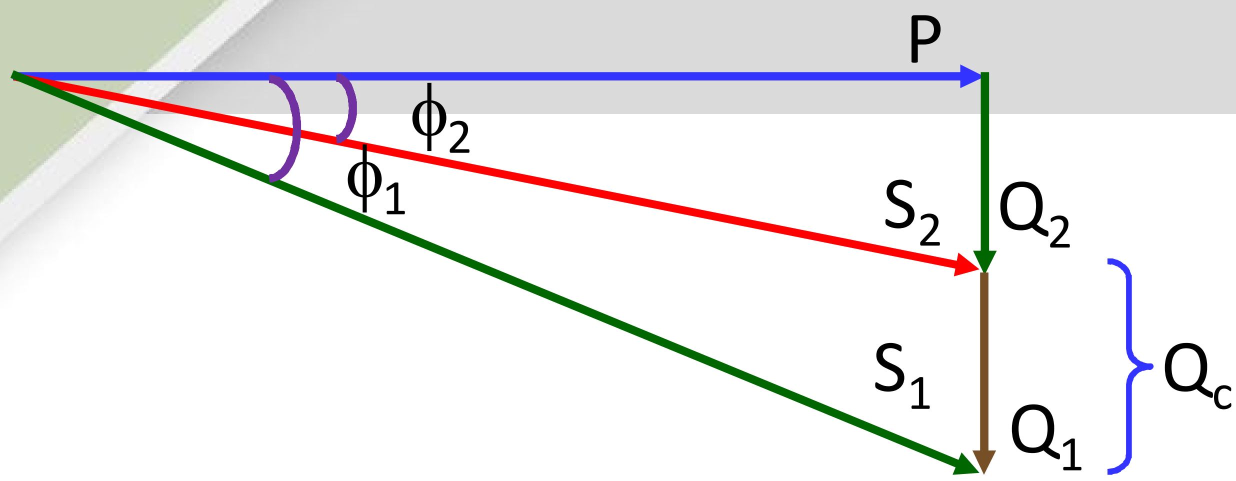
Optimal Correction of Power Factor



Annual saving = $A(S_1 - S_2)$

"A" is the cost of kVA (L.E./ kVA), "S_1" and "S_2" are the apparent power before and after correction

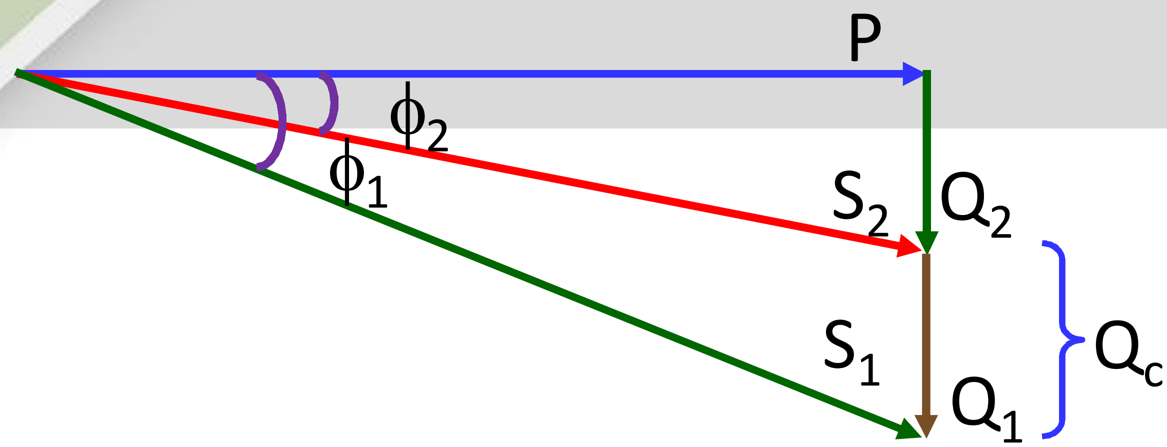
Optimal Correction of Power Factor



$$\textit{Annual saving} = Sav = A\left[\frac{P}{\cos(\varphi_1)} - \frac{P}{\cos(\varphi_2)}\right] \qquad \text{(L.E./year)}$$

The price of the capacitor bank depends on the reactive power capacity

Optimal Correction of Power Factor



$$\textit{Net Annual saving} = Sav_{net} = A\left[\frac{P}{\cos(\varphi_1)} - \frac{P}{\cos(\varphi_2)}\right] - \frac{B.b}{100}(Q_1 - Q_2)$$

The term $\frac{B.b}{100}(Q_1 - Q_2)$ is the capacitor cost with "B" the unit cost of the capacitor reactive power cost and b/100 is the annual amount

Optimal Correction of Power Factor

$$Sav_{net} = A.P\left[\frac{1}{\cos(\varphi_1)} - \frac{1}{\cos(\varphi_2)}\right] - CP\,(\tan(\varphi_1) - \tan(\varphi_2))$$

Where C is a constant: $C = \dfrac{B.b}{100}$

$$\frac{\partial Sav_{net}}{\partial \phi_2} = 0:$$

$$0 = A.P\left[-\frac{\sin(\varphi_2)}{\cos(\varphi_2))^2}\right] - CP\left(-\sec^2(\varphi_2)\right)$$

$$0 = A\left[-\frac{\sin(\varphi_2)}{\cos(\varphi_2))^2}\right] + C\left[\frac{1}{\cos(\varphi_2))^2}\right]$$

Optimal Correction of Power Factor

$$0 = A\left[-\frac{\sin(\varphi_2)}{\cos(\varphi_2))^2}\right] + C\left[\frac{1}{\cos(\varphi_2))^2}\right]$$

Or $A\sin(\varphi_2) = C$

Thus $\sin(\varphi_2) = \dfrac{C}{A}$

And $\cos(\varphi_2) = \sqrt{1-\left[\dfrac{C}{A}\right]^2}$